LARGE SCALE ESTIMATION OF BIOMASS INCREMENT BY COMBINING TERRESTRIAL AND SATELLITE DRIVEN DATA

Authors: Hasenauer H[1], Neumann M[1], Moreno A[1], Köhl M[2], Mues V[2], Mäkelä A[3], Härkönen S[3], Chirici G[4], Mura M[4], Dragoi M[5], Bouriaud O[5], Lang M[6], Muys B[7], Achten W[7,13], Thivolle-Cazat A[8], Zasada M[9], Bronisz K[9], Svoboda M[10], Merganicova K[10], Mohren F[11], Decuyper M[11], Alberdi I[12], Astrup R[15]

1) Institute of silviculture, Department Wald und Bodenwissenschaften, University of natural resources and life sciences, Vienna, Peter-Jordan-Str. 82, A- 1190 Wien
Tel: ++43-1-47654-4051
e-mail: hubert.hasenauer@boku.ac.at
2) Institute for World Forestry, Centre of Wood Science, University of Hamburg (UHH), Leuschnerstr. 9, D-21031 Hamburg, Germany
3) Department of Forest Sciences, University of Helsinki (UHEL), P.O. Box 27 (Latokartanonkaari 7) FI-00014 University of Helsinki, Finland
4) University of Molise (UNIMOL), Via Francesco de Sanctis, 1, 86100 Campobasso, Italy
5) Universitatea Stefan del Mare (USV), Suceava, Str. Universitatii, nr. 13, cod postal 720229, Suceava, Romania
6) Tartu Observatory (TO), 61602 Tõravere, Estonia
7) KU Leuven – University of Leuven (KULEUVEN), Division Forest, Nature and Landscape, Celestijnenlaan 200E – 2411, BE-3001 Leuven, Belgium
8) Forêt Cellulose Bois-construction Ameublement (FCBA), 10 avenue de Saint-Mandé, 75012 Paris, France
9) Department of Dendrometry and Forest Productivity, Warsaw University of Life Sciences (SGGW), Nowoursynowska 159, 02-787 Warszawa, Poland
10) Czech University of Agriculture in Prague (CZU), Faculty of Forestry and Environment, Kamycka 129, 16521 Prague 6, Czech Republic
11) Wageningen University (WU), Forest Ecology & Management, P.O. Box 47, 6700 AA Wageningen, The Netherlands
12) INIA-CIFOR, Departamento de Selvicultura y Gestión de los Sistemas Forestales. Ctra. A Coruña, km 7,5. 28040 Madrid, Spain
13) Université Libre de Bruxelles (ULB), Institute for Environmental Management and Land Use Planning (IGEAT), Avenue Franklin D. Roosevelt 50 CP 130/02, B-1050 Brussels, Belgium
14) Finnish Forest Research Institute (METLA), Yliopistokatu 6, BOX 68, FI-80101 JOENSUU, Finland
15) Norwegian Forest and Landscape Institute (NFLI), Høgskoleveien 8, Postboks 115, 1431 Ås, Norway

1 ABSTRACT:

A concept of reconciling different data sources for net primary productivity (NPP) was tested and successfully applied using an improved satellite-based NPP dataset and the results of forest inventory datasets from 13 European countries.
NPP estimates using satellite data represent, similar as the results of biogeochemical simulation models, a potential, which is not reached in most cases. Stand density is the key variable to explain discrepancies between satellite-driven and terrestrial NPP estimates. Other variables like location, elevation, or tree age proofed to be not relevant. Stand density is a surrogate for inter-tree-competition and is in Europe mainly affected by management and disturbances. By combining these two data sources one can derive realistic large scale forest productivity estimates in an efficient way and utilize the strength of both, the complete coverage of large areas with satellite-driven data and representation of the actual forest conditions by the terrestrial data.
Understanding, combining and utilizing available data sources is important for any project dealing with climate change, carbon sequestration, carbon neutrality or forest ecosystem management, particulary in regions, which lack forest inventory data or feature a large forest cover.

Keywords: forestry, biomass production, CO2 balance

2 INTRODUCTION:

Accurate and reliable estimates of biomass stocks and biomass increment rates are important for many purposes. Examples are projects doing research on ecosystem dynamics, remote sensing, climate change or carbon sequestration but also monitoring systems like REDD-project reportings or carbon reporting protocols (like the Kyoto protocol). Large-scale estimates are of particular importance in case of limited availability of terrestrial data large areas and/or if very big areas have to be consistently investigated. Net Primary Productivity (NPP) is a measure for carbon uptake by plant ecosystem. The unit of NPP is amount carbon per spatial unit per temporal unit, like gramm carbon/m²/year.

There are several available data sources for NPP, terrestrial measurements of biomass allocation or flux dynamics (bottom-up), space-based models (top-down). Biomass allocation can be derived from sample plots that are repeatedly measured. Experimental research plots or regular inventory systems. For assessment of the state and condition of forests in many countries of the world "national forest inventory systems" (NFI) were established [19].

Another terrestrial based data source are flux towers [1, 2]. Currently about 520 flux towers are measuring and recording plant-atmosphere interactions and flux dynamics across the globe (see http://www.fluxnet.ornl.gov).

Both terrestrial data sources can be used to derive NPP estimates for a discrete number of points, namely the locations of the sample plots or flux towers.

A space based method is the MODIS NPP algorithm [17, 21]. It uses reflectance data of the earth surfaces measured by the MODIS sensor mounted on the TERRA EOS satellites and interpolated climate data. Results are available on a continuous 1 x 1 km grid across the globe. The model consider fully stocked stands and therefor provide potential productivity which is not reached if management or disturbances reduce the stocking density.
Results of current research show that terrestrial and space-based NPP estimates can be linked if data harmonization and stand density correction is applied [6, 11]. The general scheme of harmonizing and linking terrestrial and satellite based data is shown below.

This concepts allows to derive large scale estimates of actual forest productivity.

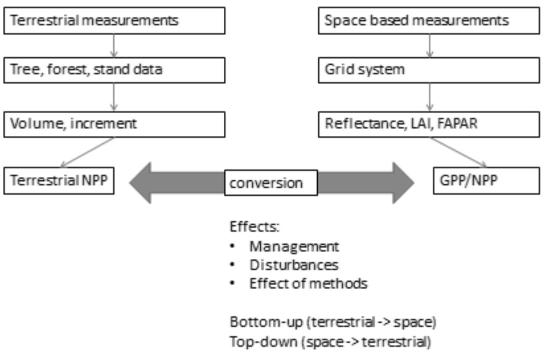

Figure 1: general concept of linking terrestrial and space-based NPP estimates

3 METHODS AND DATA

3.1 MODIS NPP - "top-down" approach

Biogeochemical models consist of relationships that model flux dynamics within plants and ecosystems. A well known example is Biome BGC [16, 18]. It provides results based on a systematic grid or on discrete points information on a number of ecosystem properties. Productivity of a plant ecosystem can be expressed by gross primary productivity (GPP) or net primary productivity (NPP). The MODIS NPP algorithm [17, 20, 21] simplifies the modelling environment of Biome BGC and uses models and components from Biome BGC making it less data dependant. It requires climate and satellite data and provides NPP and GPP results on any grid system across the globe.
The algorithm calculates *GPP* as

$$GPP = \varepsilon_{\max} \cdot 0.45 \cdot SWrad \cdot FPAR \cdot f_{VPD} \cdot f_{Tmin}$$

Where ε_{max} is the maximum light use efficiency as it depends on vegetation or biome types, *SWrad* is the short wave solar radiation load at the surface of which 45% (0.45) is photosynthetically active, *FPAR* the fraction of absorbed PAR (Photosynthetic Active Radiation), and f_{VPD} and f_{Tmin} which are multipliers between 0 and 1 addressing water stress due to vapor pressure deficit (*VPD*)

Annual Net Primary Production (*NPP*) is calculated from *GPP* by subtracting the autotrophic respiration components (i) maintenance respiration R_m and (ii) growth respiration R_g:

$$NPP = \sum GPP - R_m - R_g$$

Using radiometric information each pixel get classified according to a land cover classification system (MOD12Q1 [3]. This system differentiates among others between different forest types, agriculture land open wooded area or shrubland.

Combining productivity estimates and land cover classification it is possible to estimate productivity of forested areas.

Previous research that this model is climate sensitive and requires high quality climate to provide reasonable results [6, 11]. Therefor a downscaled climate dataset containing daily minimum and maximum temperature and precipitation on a 1 x 1 km grid [10] got used for the calculations.

3.2 NFI data – „bottom-up“ approach

Terrestrial forest growth data allow estimation of growing stock, increment, stand density, etc. If the data is collected on a systematic grid system, the results are represantative for a bigger area.

Within the Project FORMIT funded by the European Union from 13 countries in Europe terrestrial measurements from NFI systems were used to develope a consistent dataset of terrestrial productivity estimates. This happened in close cooperation with partners from the respective countries which contribute data (see figure 2 and table 1).

Figure 2: map showing Europe and countries with available terrestrial forest inventory data (hatched)

Terrestrial NPP was calculated with the approach presented in [6] by adding carbon increment of trees using data from the forest inventory data and carbon flow into litterfall estimated using climate data.

$$NPP = inc_{plot} + C_{Litter}$$

with inc_{plot} is the carbon increment of trees on an inventory plot, C_{litter} is carbon flow into litterfall calculated after [8] using the climate data of [10]

Amongst others the forest inventory datasets provide information on properties of trees like tree species, stem diameter, tree height, number of trees [19]. As the sampling systems differ, some systems offer more information.

Volume or biomass models are a concept to estimate the volume or biomass content of tree based on properties like species, diameter, height, etc. Based on literature reviews and comparative analysis for each country a set of biomass models e.g. for Norway [9, 12] or for Spain

[14, 15] and conversion factors were selected and applied to estimate carbon content of trees. 50% of dry biomass was considered to be carbon according [7].

Carbon increment then get calculated using the carbon estimates. As forest management, environmental and site conditions or genetical properties of trees vary throughout Europe, different biomass models are used. Analogue the increment calculation method varies as the forest inventory data got collected using different sampling systems (e.g. fixed area plots or sampling proportional to diameter) [5].

For assessing the stocking density and the inter-tree competition the stand density index after Reinecke [13] was calculated for the inventory plots. It was shown to be independant of site and age [4] and is a consistent measure for stand density throughout Europe.

$$SDI = Nha \cdot (\frac{dg}{25})^{1.605}$$

With *Nha* being stem number [ha^{-1}]and *dg* mean tree diameter at height 1.3 m [cm].

4 RESULTS

The MODIS NPP algorithm in combination with the downscaled climate [10] allowed the calculation of a consistent NPP dataset for Europe (see figure 3).

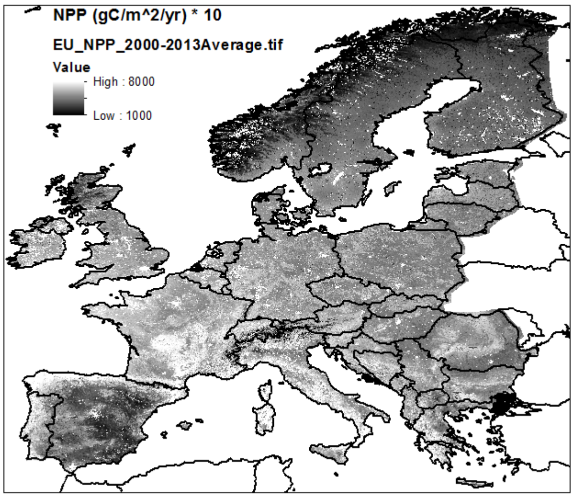

Figure 3: map of MODIS NPP for Europe (annual mean average of 2000 – 2013)

For a large number of inventory plots distributed over Europe results on productivity, stand variables, density measures and growing stock was derived. A selection of the results is shown in table 1.

country	contributing partner	no. of plots	ABG biomass [t/ha]	terrest. NPP [gC/m²/a]	SDI
Austria	BOKU	9167	162.3	390	661
Belgium	KULEUVEN	318	141.1	529	627
Czech rep.	CZU	18724	305.7	396	802
Estonia	TO	949909	88.1	319	445
Finland	UHEL	9554	78.5	286	476
France	FCBA	31475	137.3	392	488
Germany	UHH	6153	173.6	301	593
Italy	UNIMOL	19339	92.9	389	439
Netherlands	WU	442	154.4	499	577
Norway	BOKU/NFLI	18032	63.3	246	390
Poland	SGGW	14946	145.4	465	568
Romania	USV	16612	167.2	373	577
Spain	INIA/UNIMOL/BOKU	64547	69.3	324	227

Table 1: summary of results from NFI-data – partner contributing data (for abbreviations see list of authors), number of plots with data (number for Estonia indicate stands with data), mean total aboveground tree biomass, terrestrial NPP (median), Stand density index (SDI) (median)

Previous research [6, 11] showed that stand density is the key variable explaining the discrepancies between bottom-up (NFI) and top-down (MODIS) NPP estimates. The results derived within this study show the same behaviour. With increasing stand density the results of MODIS NPP and terrestrial NPP tend to converge. Some examples are shown in figure 4.

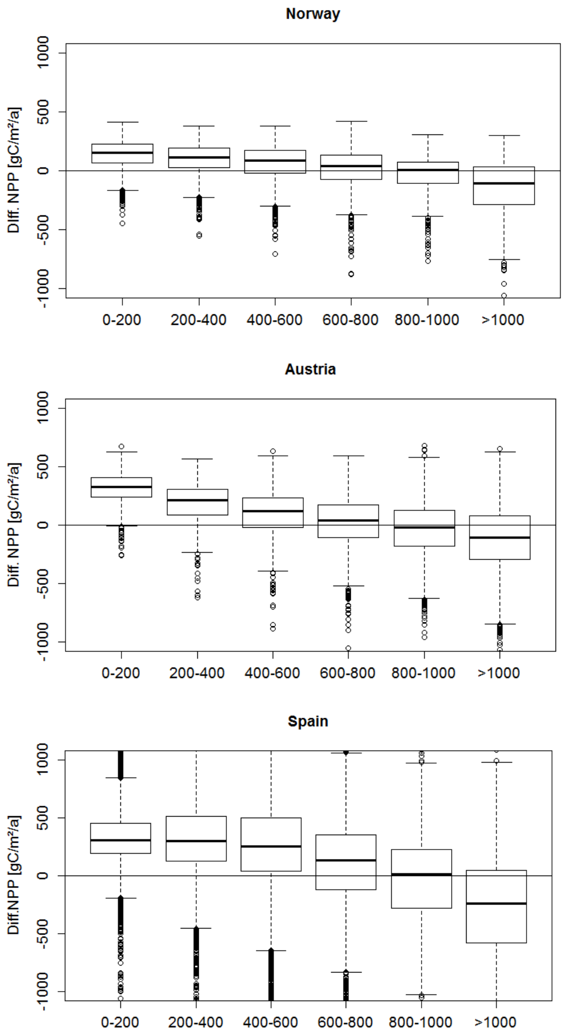

Figure 4: Difference between MODIS NPP and terrestrial NPP grouped by SDI for 3 selected countries. The box represents the Median and the 25 and 75 Quartile, the whiskers 1.5 of the interquartile range, circles are values outside this range

5 DISCUSSION & SUMMARY

Unmanaged forest stands develop high stand density, the system seeks to reach its potential stocking density [13]. Management or natural disturbances reduce this potential and mainly cause the variation in stand density visible in figure 4. Therefor stand density is a surrogate of management or disturbance intensity.

The results show that the concept of [6, 11] is also valid for other countries and inventory datasets for Europe. A consistent stand density related trend is apparent for all analyzed countries (see figure 4). Analysis of other variables like elevation, tree species, geographical location, stand age, etc. suggest that stand density is the only variable that explaines the difference between satellite and terrestrial derived NPP.

Using stand density data derived from terrestrial measurements the MODIS NPP results can be corrected to represent actual forest conditions.

To get estimates for accumulated carbon some more steps are necessary. The link between forest productivity (NPP) and stem carbon allocation has to be found. Biogeochemical models like the already used Biome BGC can be useful here. Also the question on the amount and quality of terrestrial data to reach a satisfying accuracy of the results has to get examined and answered.

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